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How cities source their food: spatial interactions in West African urban food supply

Hanna Karg^{1,2} · Imogen Bellwood-Howard³ · Navin Ramankutty¹

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Abstract

In West Africa, increasing rural–urban flows of food, driven by growing urban populations, require functional, efficient links between cities and production areas. However, underlying mechanisms of urban food sourcing in West Africa are poorly understood. This study deepens understanding of spatial interactions between cities and production areas by examining the effects of settlement size, geographical distance, and agricultural suitability on food inflows to four West African cities. The analysis was informed by theoretical spatial models and data on food flows, road network, agricultural suitability, and settlements. Results showed that food travelled further from larger supplying settlements, and towards the two larger destination cities. This supports the idea of a hierarchical system, where food provisioning area and upstream supply chain length increase with settlement size. Overall, towns with fewer than 100,000 inhabitants, often representing aggregation centres, were among the major suppliers to the cities. Complementary agricultural suitability between origin and destination shaped food flow direction and length, but poor road access and international borders impeded trade. Spatial models did not fully explain food flows: they were also influenced by historical factors shaping certain settlements' importance as sources. Study cities were supplied by a diversity of more and less concentrated food sources, representing production sites or aggregating markets, which should theoretically support food supply resilience. Improvements to storage and road infrastructure, and removing trade barriers, could improve food supply to cities, and producer and trader livelihoods. Emerging research on urban food systems governance could support understanding of how best to do this.

Keywords Central Place Theory · Food trade · Spatial Interaction Models · West Africa

1 Introduction

Cities, as net consumers of food, have always relied on other places for their food supplies, ranging from their immediate hinterland to distant global locations. In West Africa, urban populations more than doubled in the past 20 years (SWAC/OECD, 2020), contributing to greater urban food demand. Most urban West African food demand is met by domestic production, linking rural production zones with

urban consumption centres (Vorley & Lançon, 2016), where, historically, local and periodic markets have played, and continue to play, a key role (Karg et al., 2019a; Porter et al., 2007).

Increasing urban demand therefore influences upstream distribution and production, e.g., by stimulating rural production to become more market oriented (de Bruin et al., 2021). Much of the existing food trade in West Africa can be defined as 'informal', providing livelihoods for producers, transporters, and traders, often women (Porter et al., 2007). Women and those who lack resources to enter more exclusive value chains have historically found livelihoods in traditional food markets connecting urban and rural areas, while those with better access to resources tend to join more formalised and international value chains (Dzanku & Hodey, 2022; Isinika et al., 2021). Meanwhile, authors writing about foodsheds, city region food systems and urban food sovereignty have recognised that better rural–urban links can support urban food security (Battersby & Watson, 2019),

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and that the nature of these links is influenced by the degree of formalisation and the style of urban governance in a city and region (Smit, 2016).

Data on official trade flows do not effectively capture the full range of informal and formal trade that supplies cities, despite its importance to food security and livelihoods. Since informal trade is particularly common in African cities, there is a need to better understand how African cities source their food in general, and specifically how cities of different sizes and with different functions in different agroecological zones connect to production zones via markets. Understanding spatial aspects of cities' food supplies could help guide infrastructural, planning, regulatory and governance changes that are needed to facilitate food flows that support livelihoods and food security. Understanding how distant places are connected to cities via telecoupled flows of food can also advance understanding of processes in the production regions, including potential effects of agricultural and other policies on farm decision making and land use change (Liu et al., 2013). Furthermore, analysis of mechanisms of rural-to-urban food flows can support an understanding of how people and settlements are integrated into commercial food trade networks and provide ideas for enhancing the economic integration of remote regions, with implications for inclusive development and equality.

Therefore, the aim of this paper is to provide a better understanding of spatial interactions between West African cities and food production areas in the West African region. We rely on a unique food flow data set that captures formal and informal food flows for four West African study cities — Bamako (Mali), Ouagadougou (Burkina Faso), Tamale (Ghana), and Bamenda (Cameroon) — as well as secondary data. Informed by theoretical models and the specific agri-food context, we examine:

- Rural-to-urban food flows and how they are shaped by agricultural suitability, international borders, road access, travelled distance, and intermediary markets (hypotheses 1–6; see below).
- How and why urban supply chains differ in their levels of concentration and in terms of geographical distance between suppliers and a given destination city.

To describe conditions for spatial flows of goods and people between different locations, spatial models, such as Central Place Theory (CPT; Christaller, 1968) and spatial interaction models, including the gravity model (Wilson, 1971), have been developed. These models have in common principles such as diminishing influence with increasing distance between origin and destination, and growing influence with increasing size of a place. They can be applied to the movement of food between a city and its food suppliers. CPT considers the spatial configuration of settlements and

their catchments in a hierarchically nested manner. Spatial interaction models, on the other hand, consider the complementarity between source and destination, which can explain horizontal flows between places of the same size. Combining these theories with what is already known from literature about factors that affect food flows, we pose the following hypotheses:

1. The quantity of food supplied increases with increasing complementarity, i.e., with increasing gradient in agricultural suitability between origin and destination.
2. International borders impede the transport of goods, i.e., a larger quantity of goods travels between two settlements when there is no international border between them.
3. The quantity supplied increases with the proximity of supplying settlements to roads.
4. Larger settlements have a larger catchment area, both as a source (sender) of and a destination (recipient) for food flows.
5. Larger settlements supply larger quantities.
6. The overall supplied quantity decreases with increasing distance between origin and destination.

After addressing these hypotheses, we further examine the level of concentration and the average distance travelled in product-specific supply chains.

The paper is organised as follows: Section 2 describes how food supply and demand are connected through markets in the context of West Africa. Section 3 describes the theoretical framework and the methodology used. The results and discussion section (Section 4) presents and discusses results relevant to each of the six hypotheses, shows how concentration and geographical distance vary across supply chains, and considers research and policy implications. Section 5 concludes the paper.

2 Food supply in West Africa

2.1 Demand

The West African urban population doubled between 2000 and 2015, while the total population increased by 57%.¹ Today, the urban population is almost half of the total population (48%; SWAC/OECD, 2020). Thus, overall regional food demand, and in particular urban demand, has risen. Traditionally, West African diets are high in carbohydrates (Bosu, 2015), supplied mostly by products adapted to local

¹ West Africa according to the African Union region definition plus Cameroon.

and regional agricultural conditions. Coastal countries in West Africa traditionally rely more on roots, tubers, and plantain than countries in the Sahel that consume more cereals, such as sorghum and millet (Elbehri et al., 2013). However, there has been an increase in imports of cereals, in particular rice and wheat, in recent decades in response to a growing urban population. For example, consumption of rice, much of which is imported, has risen across the region since the 1970s because of its labour-saving preparation (Moseley et al., 2010). Undernutrition remains present in rural and, to a lesser degree, urban areas across West Africa (van Wesenbeck, 2018). Increased urban population has increased marketed share of food and shifted demand toward more processed, prepared, and perishable foods, owing to a growing urban middle class (Tschirley, 2020; Zhou & Staatz, 2016). Specifically, in West Africa, urbanites and people with higher incomes tend to consume more easy-to-prepare meals, processed and ultra-processed foods, and meals away from home (Thériault et al., 2024). This also means that wealthier rural people adopt new consumption patterns. Overall, rural people are now largely net food buyers (Bricas et al., 2016), meaning they rely on markets for food security as well as income, often selling legume and vegetable produce to buy staples.

2.2 Supply

Most Sub-Saharan African food demand has historically been met by domestic production, with imports accounting for 1–3% of total food consumed between 2002 and 2011 (Vorley & Lançon, 2016). West Africa is self-sufficient in most of the region's needs for coarse grains, tuber and root crops, vegetables, fruits, and meat (de Steenhuijsen Piters et al., 2021). Due to its strong climatic gradient, the region accommodates a wide variety of agroecological zones and farming systems, ranging from pastoral in the far north to tree-crop systems in the south (Garrity et al., 2017). Despite ongoing urbanisation, more than one third of the West African population still engages in farming (Hollinger & Staatz, 2015). This comprises mostly rural family farms with varying degrees of specialisation and commercialisation, meeting most urban demand through informal value chains (de Steenhuijsen Piters et al., 2021; Hussein & Sutties, 2016).

2.3 Connecting supply and demand

Since pre-colonial times, traders and markets played an important role in West Africa's food system (Porter et al., 2007). Up to today, traditional periodic market networks present a major marketing channel for food trade, illustrated by Karg et al. (2019a) for cereal trade in north-eastern Ghana. Traditional local markets, involving wholesale and retail sale in open markets, neighbourhood stores and informal food

vendors, still dominate the food trade sector in West Africa (Hollinger & Staatz, 2015), unlike in East and South Africa where corporate supermarkets are more common (Holdsworth & Landais, 2019; Reardon & Gulati, 2008). While more formal systems can potentially provide better traceability and food hygiene of perishable goods, involvement in local food systems has tended to provide a low capital entry income opportunity for small scale bulkers, retailers, and wholesalers, who, especially in the West African context, are usually women (Porter et al., 2007). Much of this trade is labelled 'informal' or 'traditional' (Poulton et al., 2000), however, 'traditional' markets are gaining characteristics of the 'formalised' markets found elsewhere – for example processing and packaging components for products such as cereal flour may become corporatised rather than operating at the cottage scale, resulting in what could be called a hybrid system. This hybridity mirrors the nature of urban governance in West Africa, where control over and access to resources such as space, and provision of services such as transport infrastructure, is influenced by multiple institutions not limited to local administrative government, but also including traditional authorities, trade associations and civil society organisations (Olivier de Sardan, 2011; Smit, 2016).

Growing rural–urban supply chains mean that urban catchments expand, and spatial supply lines elongate (Haggblade, 2020) requiring more facilities, infrastructure, and services. This is reflected in the rapidly developing non-farm food economy, which generates 40% of the added value of the overall food economy (Allen & Heinrigs, 2016). These 'mid-stream segments' include wholesale and retail distribution systems, warehousing, cold storage, food preservation, processing, and packaging (Reardon, 2015), in which cities play an increasingly important role (Haggblade, 2020). For instance, cities act not only as consumption centres, but also as aggregation centres for further redistribution (Karg et al., 2022). In many cases, this provides jobs to residents, including migrants, in rural towns and larger cities. Traditionally, many agricultural processing and trading roles have been filled by women (Poulton et al., 2000; Torvikey & Dzanku, 2022), providing them with income.

3 Materials and methods

3.1 Theoretical framework

In addition to the demographic, historical and biogeographical context, we draw on previously developed models to describe conditions for spatial flows of goods and people between different locations.

To explain the movement of goods in a hierarchical system of markets or settlements, scholars have drawn on elements from the Central Place Theory (CPT), originally

developed by Christaller (1968). For instance, mid-twentieth century geographers and anthropologists described hierarchical components to many of the periodic markets across different areas of West Africa, and central place theories were relevant to some degree in many of them (Hill, 1966; Smith, 1971). Thereby, food flows occur between hierarchical levels, and low-level markets are nested within the catchments of higher-level markets. The CPT has been criticized for lacking consideration of specialisation and resulting horizontal flows between cities of equal sizes in a network of cities, which led to changes and extensions of the model (e.g. central flow theory by Taylor et al., 2010; Krmenec & Esparza, 1993).

The gravity model, an early example of a spatial interaction model, was applied to international trade (Isard, 1954) and considers the intensity of an interaction, such as trade flows, between two places as a function of their mass and distance. Thereby, the interaction between two places is proportional to their mass, such as population size, and diminishes with distance (O'Kelly, 2009). Based on the gravity model, a family of spatial interaction models was developed (Wilson, 1971). These generally consider three factors for the exchange of goods between two places: 1) spatial separation or transferability, often represented by a distance- or travel time decay function, 2) complementarity, and 3) intervening opportunity. Complementarity is considered high between a place with surplus crop production and a place demanding that crop. Intervening opportunities are

related to distance decay and “impede interaction between distant places because the same goods and services are available at closer locations” (Ullmann, 1956, cited by Krmenec & Esparza, 1993). Building on CPT and gravity models, literature in economic geography also notes that the location of production of a good is influenced by the availability of relevant factors of production, such as labour (Venables & Limao, 2002; Overman et al., 2003).

Based on the theoretical and contextual considerations shaping urban food supply in West Africa outlined in the previous sections, we developed our conceptual framework (Fig. 1) depicting drivers of rural-to-urban food flows in West Africa, operationalised as relative product-specific quantities flowing from geographical sources, and summarised in hypotheses 1–6. The drivers considered here were analysed at the regional level (flows aggregated by categories, see Fig. 1) as well as at the level of individual suppliers (flows aggregated by supplying source settlement). This allowed us to distinguish between relationships associated with the share of inflows from areas characterised by categorical data (e.g., flows from sources with primary road access, or flows from the hinterland), and the relationship between characteristics of individual supplying source settlements, such as settlement size and distance to the study city, represented by numerical data. For instance, based on spatial interaction models, we hypothesise that cities tend to source from nearby locations unless specific products are unavailable, e.g., due to low agricultural suitability. Good

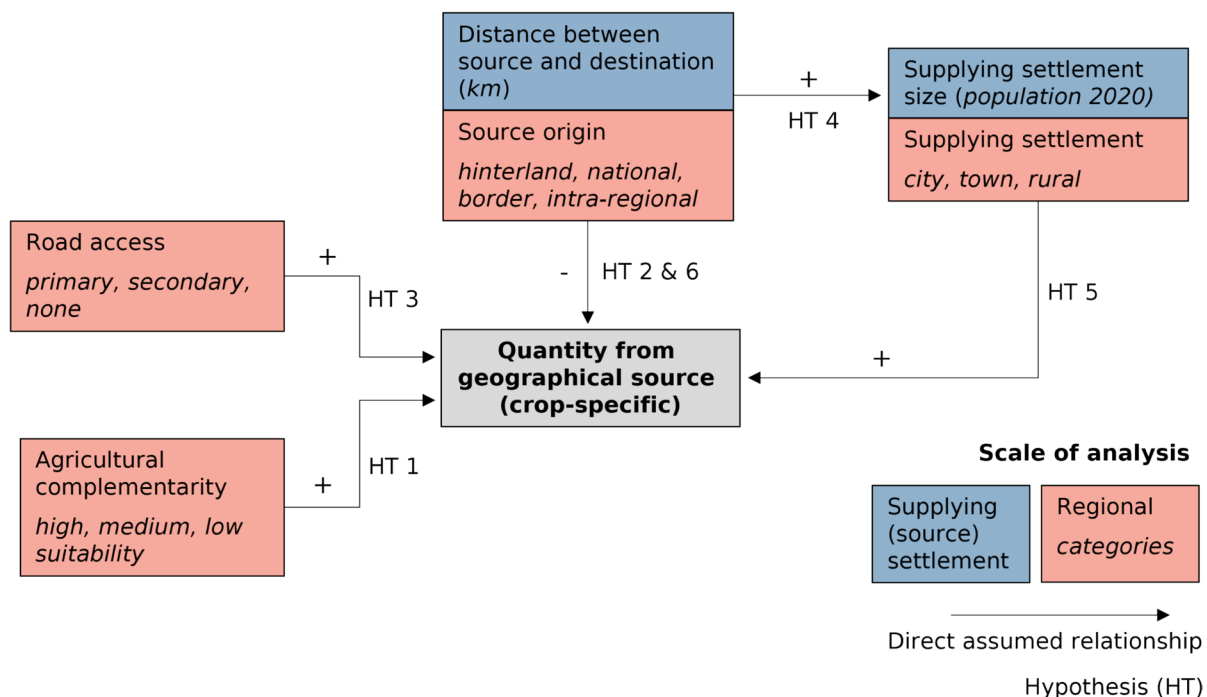


Fig. 1 Conceptual framework summarising drivers for rural-to-urban food flows in West Africa at the regional scale and the scale of supplying source settlements. Note: terms related to the categories are defined in section 3.4

road access increases accessibility, while international borders are substantial trade barriers and increase travel time and cost, making domestic (i.e., national) sources more attractive. The CPT suggests flows from a larger source settlement are more likely to travel longer distances than flows from smaller settlements. Larger settlements not only have larger catchment areas, they also provide larger quantities, based on the main premise of gravity models.

3.2 Data

3.2.1 Primary data

This analysis used food flow data collected between 2014 and 2017 from four study cities in West Africa, as part of the UrbanFoodPlus² project on urban and peri-urban agriculture in West African cities: Bamako, Mali; Ouagadougou, Burkina Faso; Tamale, Ghana, and Bamenda, Cameroon. Bamako and Ouagadougou are capital cities having over 2 million inhabitants at the time of data collection, while Tamale and Bamenda are regional capitals, which had over 300,000 residents (SWAC/OECD, 2020). While Bamako and Ouagadougou are in landlocked Sahelian countries, Tamale and Bamenda are in countries with access to ports. Tamale and particularly Bamenda have significantly higher rainfall than the Sahelian cities and consequently different agricultural conditions. The dataset comprises flows of unprocessed food collected on all transport routes to the city, mainly on the road (Karg et al., 2023). Specifically, information such as geographical source and destination, and the type and quantity of goods, was collected from vehicles carrying food products into or out of the city, ranging from motorbikes to large trucks. This was done for multiple seasons for about one week per season, day and night, to capture all food-stuff coming into the city or going out during this period. The original dataset contains product-specific inflows, outflows, and transit flows,³ representing individual trips with geocoded origin and destination, and has more than 100,000 records. Specifically, for each study city, we used the geocoded source location and the quantity provided by the source (daily quantity in kg/day; % of total quantity per product; and mean transport load in kg/trip).

This paper relies only on inflows to cities during the main harvest season (between October and December for Bamako (2015), Ouagadougou (2014), and Tamale (2014), and for February 2017 for Bamenda) for selected products (Table 1), which are largely produced and traded within the

Table 1 Commodities studied

Food group	Commodity
Cereals	Maize
	Millet
	Sorghum
Legumes	Groundnut
	Pulses (incl. bean, bambara bean, cowpea)
Roots, tubers, and plantain	Yam
	Plantain
Vegetables	Tomato
	Cabbage
	Eggplant
Fruits	Orange
	Banana
	Watermelon
Livestock	Cattle
	Sheep

West African subregion, comprising ECOWAS⁴ countries and Cameroon. Since the focus of this paper is on spatial interactions between cities and their food production areas in the West African region, products from international sources beyond the West African subregion were excluded from the analysis. This also includes products that are partly imported, such as rice, and seasonally imported products, such as onion that is produced in the West African subregion during the dry season and imported from international sources in the off-season.

3.2.2 Secondary data

In addition to the food flow data, we used secondary data to characterise the places of demand and supply. These include:

- crop-specific agricultural suitability (GAEZ4: Global Agro-Ecological Zones, version 4)
- international boundaries (Bjørn Sandvik, thematicmapping.org, 2009)
- the national road network (OpenStreetMap, 2021)
- geocoded settlement data (OECD/SWAC, 2020)

The GAEZ4 data on crop-specific agricultural suitability are based on 1) edaphic characteristics, including soil and slope and 2) the agro-climatic potential biomass and yield for different land utilisation types under different management practices (rain-fed and irrigated; low, intermediate, and high input level) (Fischer et al., 2021). The data are

² <https://www.uni-kassel.de/fb11/agrar/fachgebiete/-/einrichtungen/opats/research/completed-research-projects/urbanfoodplus>

³ Food flows passing through a city without a stop.

⁴ Economic Community of West African States.

available at a resolution of 5 arc-minutes (about 9×9 km at the equator). For our analysis, we relied on historical suitability index classes from 1 to 9 (1: highest suitability, 9: lowest suitability) for all land in a grid cell. We used suitability for rainfed crops and low input level given the overall small-scale farming context. Data were not available for livestock (sheep, cattle), eggplant, orange, and watermelon. The difference between agricultural suitability at source and destination served as an indicator for complementarity. Distance between source and destination, a central parameter in both spatial interaction models and CPT, was measured in Euclidean distance.

3.3 Processing

First, inflows in the respective season were extracted from the original dataset.

3.3.1 Agricultural suitability

To assign agricultural suitability to a source location, the suitability values were averaged over a radius of 50 km around a supplying source settlement to account for a settlement's potential own catchment area for primary produce. We are aware that the flow data do not necessarily represent the primary production zone, especially in the case of hubs, such as ports or border towns, but we assume that smaller towns and cities trade goods from their own catchment rather than from afar.

3.3.2 Road access

Access to road connection was operationalised by distance to primary road (including trunk and trunk links), or secondary road, and a place was considered to have no road access if it was not within 5 km of a primary or secondary road. Intra-regional sources, i.e., suppliers from other West African subregion countries, were assumed to have primary road access.

3.3.3 Settlement size

Further processing included linking point sources from the food flow dataset to settlements in the Africapolis database for settlements larger than 10,000 people (OECD/SWAC, 2020). Thereby, a point was classified as rural or urban, based on 1) the distance to the next settlement, available as point data, and 2) the size of this settlement. The proximity chosen varied depending on the settlement size (see also Karg et al., 2022). Note that this was not applied to the study cities, i.e., the area adjacent to the urban boundaries of the study cities was considered rural, unless it belonged to another settlement's catchment. Remaining point sources,

i.e., settlements with less than 10,000 inhabitants, were classified as rural and assigned an average population of 5,000. Intra-regional sources in the dataset sometimes lack accurate geographical information, for instance if a source was given as 'Ghana' without further specification. In such cases, the source was replaced with the major supplying settlement for the specific product containing geographical information.

3.3.4 Borders

Related to this and to account for potential hubs, such as ports or border towns, we additionally used a class 'border', which included all settlements within a 20 km radius from any international border.

3.4 Analysis

Food inflow data were analysed at three different levels of aggregation: 1) the regional level, 2) the level of supplying settlements, both to address the hypotheses, and 3) the level of products and cities to examine the concentration of product-specific supply chains.

At the regional level, relative incoming quantities (%) per product and city were aggregated based on different levels of:

- proximity
 - hinterland (within a 50 km radius of a study city)
 - national (within national boundaries but outside a city's hinterland)
 - border (less than 20 km from an international border within the West African subregion)
 - intra-regional (crossing international borders within the West African subregion)
- agricultural suitability (low: 7–9, medium: 4–6.99, high: 1–3.99)
- road access (primary road, secondary road, no access to primary or secondary road)
- settlement size (rural: 5000, town: > 10,000 & < 100,000, city: > 100,000)

Furthermore, we assessed the interactions between the different dimensions by constructing contingency tables, aggregated by categories, e.g., total flows with primary road access in the hinterland. These tables show sums of product- and city-specific relative inflows (%) rather than absolute inflows (kg/day), giving equal weight to all products and cities. Chi-squared tests were carried out to assess whether associations existed between the different variables. The contingency tables with the chi-squared test results are specified in Tables S2a-d in the supplementary materials.

We also assessed interactions between the different dimensions descriptively, using shares of inflows (%) from sources represented by different categories.

To analyse individual suppliers, the original inflow dataset was aggregated at the level of city- and product-specific supplying settlements, i.e., it contained the total product-specific contribution of a supplying settlement to a city's food supply (in absolute and relative values: kg/day and % of total product-specific quantity), mean transport load (kg), and the distance to the study city as well as settlement size. At this level, we ran linear regression models to estimate the effect of distance (km; log transformed, independent variable) on supplying settlement size (log transformed, dependent variable) on the one hand and the effect of supplier size (log transformed, independent variable) on relative quantity supplied by a settlement (dependent variable) on the other (Table 2).

Data were further aggregated at the level of product and city. First, we extracted the maximum product-specific contribution (%) from one supplier to a city's total inflows as an indication of the level of concentration of a supply chain. High values indicate a high reliance of a city on a specific supplier, hence a high concentration, whereas a low maximum value means there are several suppliers contributing relatively equally to the city's supply. Then, this was plotted against mean weighted distance (km; log transformed) between supplier and destination, with the symbol size reflecting mean weighted transport loads (t/trip).

The Python script for data processing and analysis is made available at <https://github.com/HannaKarg/food-supply-model>.

4 Results and discussion

4.1 Cities consume more products that are grown in the regions where they are located

The geographical areas suitable to produce different crops vary. For instance, maize can be produced across West Africa, while the best conditions for millet are found in a narrower belt across the Sahel. Yam can be grown in the 'root and tuber crop zone' in coastal countries, and suitable production areas for banana and plantain are in the humid tropics (Fig. 2; Fig. S1 in Supplementary Materials). Inflows reflected this pattern and were often higher for given crops in cities located in zones with suitable production conditions for those crops. Bamenda, located in the tropical highlands, had by far the largest plantain inflow, and yam inflow dominated in Tamale (Northern Ghana), whereas the Sahelian cities Bamako and Ouagadougou showed much smaller inflows of these crops (Fig. 3). Inflows of the Sahelian crops millet and sorghum were not recorded at all in Bamenda. Maize inflows were high in all cities, particularly Tamale and

Ouagadougou, which act as maize trade hubs (Karg et al., 2022). In Bamako and Ouagadougou, maize inflows even exceeded inflows of sorghum and millet, which have historically been the major calorie suppliers for Sahelian countries (Haggblade, 2012). This may be because of changing consumption patterns, or because millet and sorghum are more commonly subsistence crops and less commonly marketed than maize (Bricas et al., 2009; Elbehri et al., 2013). In other cases, however, inflows did not reflect suitability levels. For instance, inflows of pulses were highest in Bamenda and Tamale despite higher suitability in the Sahel. Suitability data were poor or unavailable for most vegetables, fruits, and livestock, and it is likely that for vegetables, other factors such as proximity to irrigation water may play a more important role (Fig. 4).

4.2 Complementarity facilitates food flows, but international borders interfere

The effects of international borders were best understood when we examined regional level data on complementarity or suitability gradients. These data partially supported hypothesis 1 and supported hypothesis 2.

Reliance on cross-border trade flows, including intra-regional flows and flows originating from border settlements, was high when agricultural suitability was significantly higher in neighbouring countries. This was the case for plantain inflows in Bamako, and yam inflows in Ouagadougou with nearly 100% from across the border or the border area (Fig. 3 & Fig. 4). However, cross-border trade was weaker when a suitability gradient was less steep. For instance, Tamale, located in a country with medium suitability levels for millet, sourced 81% of its millet supplies from domestic sources despite higher suitability levels in neighbouring Burkina Faso (Fig. 4). Thus, our data suggest intra-regional borders are a major trade barrier, and often only worth crossing if a product is far less available within national boundaries. Even then, quantities provided by intra-regional sources remained small, as for orange, yam and plantain flows into Ouagadougou and Bamako (Fig. 4).

This was different for goods moving within national boundaries: where agricultural suitability gradients were pronounced, larger quantities of food moved even over longer distances and almost 80% of food came from national sources beyond the 50 km hinterland radius compared with only 10% from within the hinterland. However, where the suitability gradient was less steep, cities relied relatively more on local sources (47% from outside the hinterland; 40% from within the hinterland) (Tables S2a & S3: Supplementary Materials), supporting the principle of "intervening opportunity" suggested by spatial interaction models (Krmenc & Esparza, 1993),

Table 2 Summary of analyses performed

Hypothesis	Level of analysis	Analysis methods/ tools
1. The quantity of food supplied increases with increasing complementarity, i.e., with increasing gradient in agricultural suitability between origin and destination	Regional (sections 4.1 & 4.2)	Descriptive statistics: % of total product-specific inflows from high, medium and low suitability areas for each study city; daily per capita inflows of selected products (in g/cap/day)
2. International borders impede the transport of goods, i.e., a larger quantity of goods travels between two settlements when there is no international border between them	Regional (section 4.2)	Descriptive statistics: % of total product-specific inflows from hinterland, other national and intra-regional sources for each study city; agricultural suitability gradient between food suppliers and study cities
3. The quantity supplied increases with the proximity of supplying settlements to roads	Regional (section 4.3)	Descriptive statistics: % of total product-specific inflows from areas with access to primary, secondary, or no roads for each study city
4. Larger settlements have a larger catchment area, both as a source (sender) of and a destination (recipient) for food flows	Supplying settlement (section 4.4)	OSL linear regression model (for each study city): supplying settlement size (log transformed)~distance (km; log transformed)
5. Larger settlements supply larger quantities	Regional (section 4.5)	Descriptive statistics: % of total product-specific inflows from rural areas, town, or cities for each study city
	Supplying settlement (section 4.5)	OSL linear regression model (for each study city): % of total product-specific inflows from settlement~supplying settlement size (log transformed)
6. The overall supplied quantity decreases with increasing distance between origin and destination	Regional (section 4.6)	Descriptive statistics: % of total product-specific inflows from hinterland, other national and intra-regional sources for each study city

To test bivariate interactions between regional level data, chi-square tests were performed on the sum of product-specific inflows across all study cities (%) for hypotheses 1-5

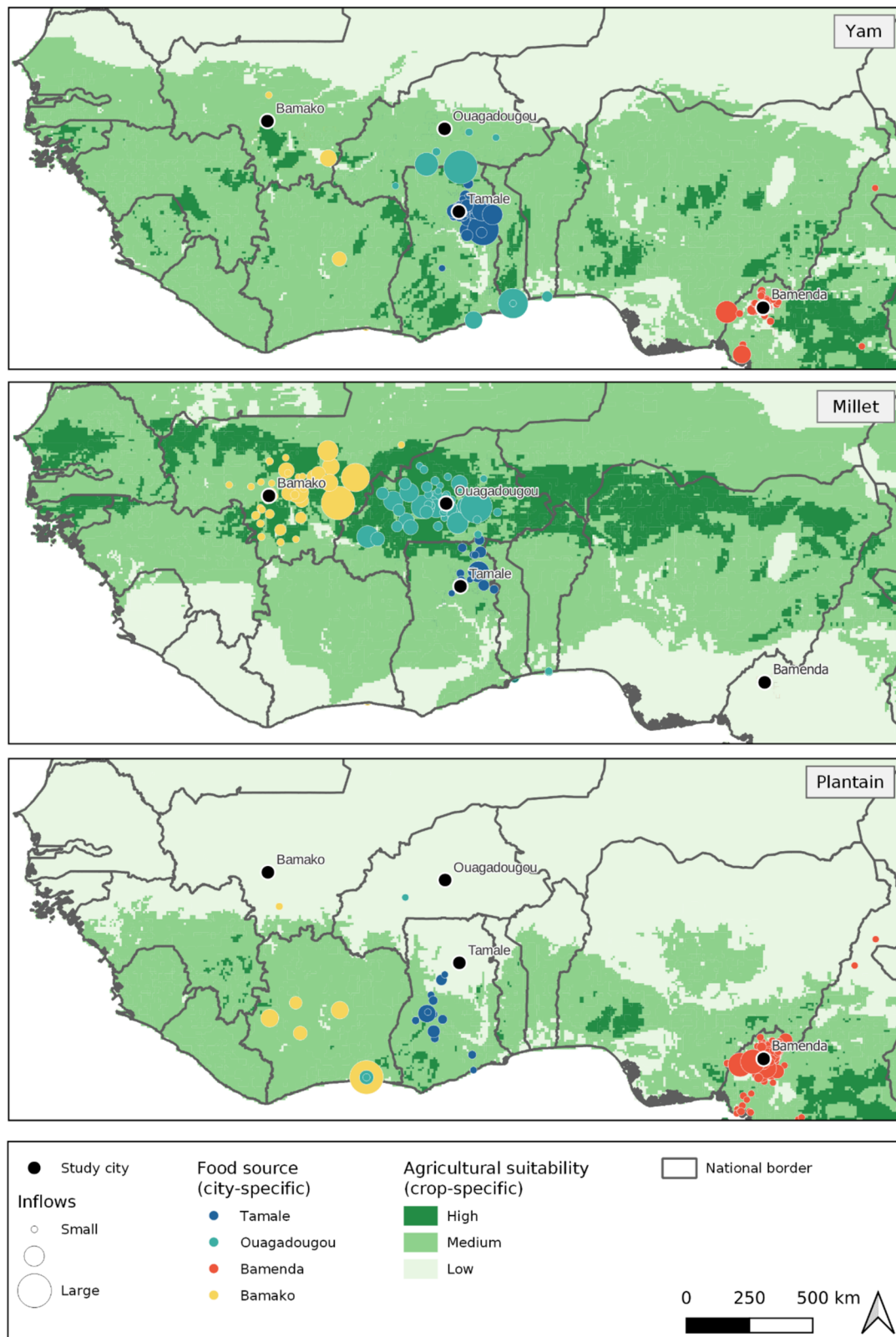


Fig. 2 a-c Geographical sources of yam, millet, and plantain and daily inflows provided by these suppliers to Bamako (Mali), Ouagadougou, (Burkina Faso), Tamale (Ghana), and Bamenda (Cameroon),

and crop-specific agricultural suitability. Note: inflows present absolute values and are comparable across countries for one product, but not across products

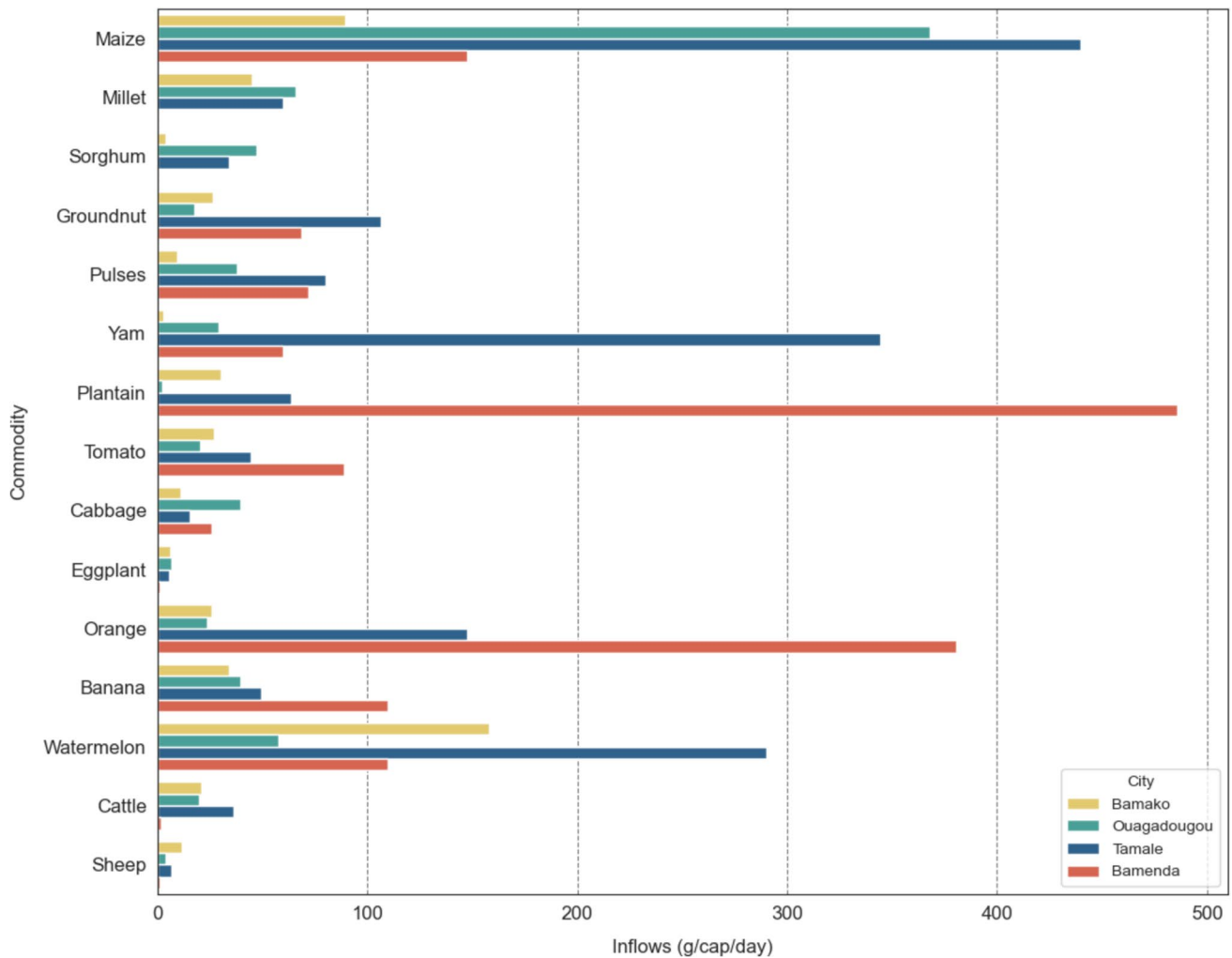


Fig. 3 Daily per capita inflows (g/day/cap) of selected products for Bamako (Mali), Ouagadougou, (Burkina Faso), Tamale (Ghana), and Bamenda (Cameroon)

according to which goods and services available in closer locations impede interaction between distant locations for the same goods.

Therefore, the presence of international borders for intra-regional trade, unlike distance for national trade, interfered with the positive relationship between complementarity and quantity supplied. Despite an increase in intra-regional trade flows in the past decades (Hollinger & Staats, 2015), our data reflect the well-documented barriers which limit the full potential of trade in the West African subregion (Akoto-Danso & Karg, 2020; Torres & van Seters, 2016), including formal and informal tariffs, varying standards and weak cross-national trader networks. Thus, national production is a pivotal food supplier for the cities, and major flows are of goods for which suitability within national boundaries is high.

4.3 Road networks facilitate trade

The data confirm the importance of road networks in facilitating movement of food, supporting hypothesis 3. In all cities, most flows originated from sources with primary road access, i.e., within 5 km of a primary road (Fig. 4). For instance, in Bamenda, only pulses, sheep, and tomatoes had primary road access of below 50% and only maize sources had no access to primary or secondary roads in over 10% of flows (17%). In Bamako and Ouagadougou, almost 70% (69%) of incoming quantities per product had primary road access. Tamale had lowest access to primary roads overall; but even there, more than 70% of total flows originated from places with primary road access. These high shares underline the crucial importance of road infrastructure for trade, in turn highlighting the vast unserved areas in these countries

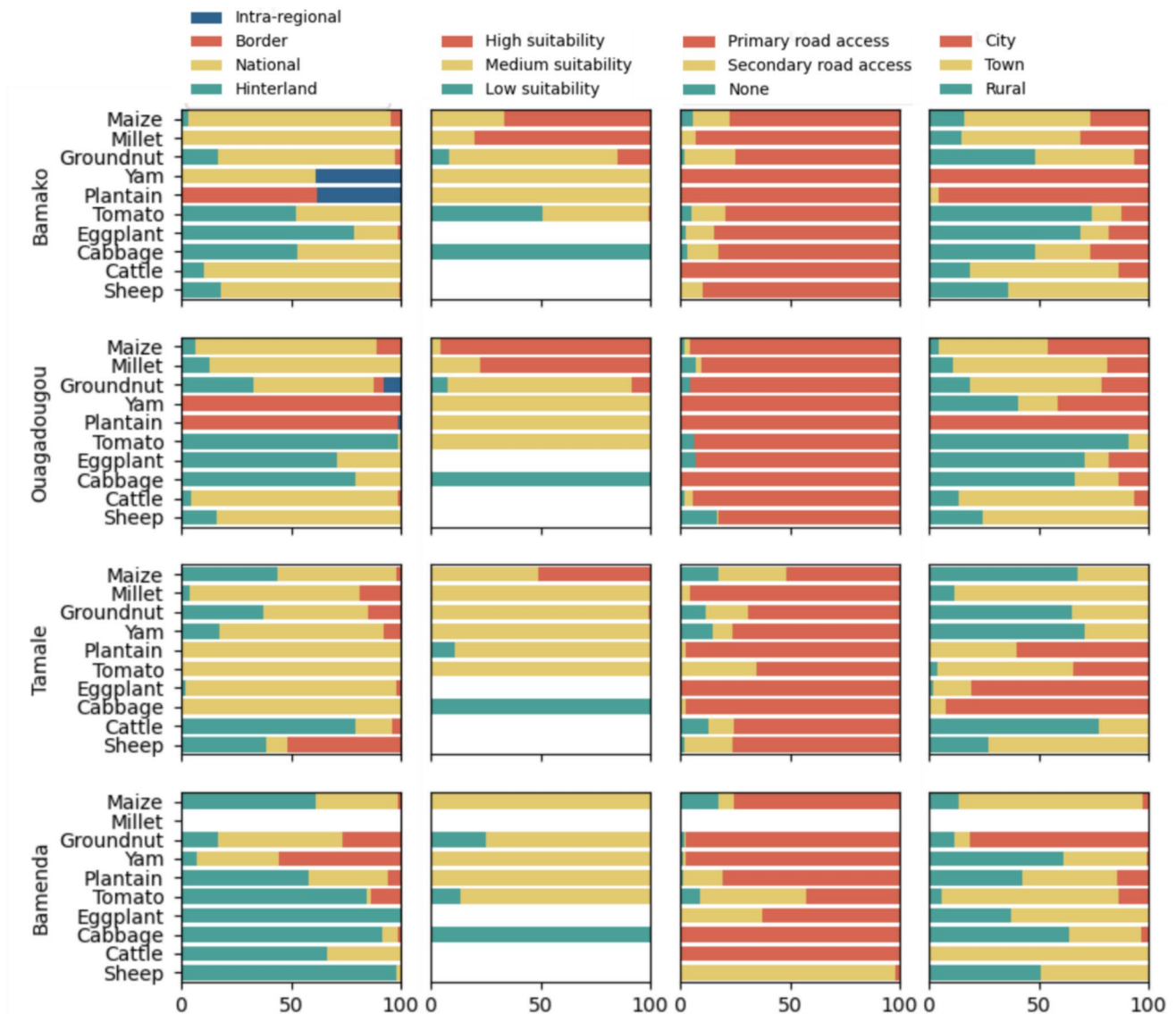


Fig. 4 Product- and city-specific relative quantities (%) from different spatial categories, agricultural suitability zones, sources with varying road access, and settlement classes for the four West African cities

and for selected products (see Table S1 in Supplementary Materials for complete list of products)

(Fig. S2: Supplementary Materials). According to Elbehri et al. (2013), the lack of well-maintained road infrastructure is a major impediment to economic integration and considerably raises market risk.

In general, our data showed that primary road connection was more common for long-distance national flows than for hinterland flows from within 50 km of the city, which is unsurprising, given good road connections decrease travel time and hence cost. For all cities but Ouagadougou, the smaller share of hinterland flows with primary road access was compensated for by greater access to secondary roads, resulting in a significantly higher overall share of flows with secondary road access from the hinterland (secondary road

access in the hinterland was 28%pt. (Bamenda), 18%pt. (Bamako), and 25%pt. (Tamale) higher than secondary road access of the remaining national sources; Tables S2b & S4: Supplementary Materials). Only for Tamale was the share of suppliers without access to either a secondary or a primary road significantly higher than for the other cities (20% of food flows from the hinterland, 12% of food flows from the remaining national sources). This means that primary road access is an important condition for long-distance inter-city flows, and even for hinterland flows, primary road access dominated, albeit with a higher share of secondary road access. The results highlight the importance of primary and secondary road infrastructure for producers to access

markets (Torres & van Seters, 2016; Wiggins et al., 2011). Such infrastructure is largely the remit of local and national formal government bodies. Constructing joined up networks across administrative boundaries can be challenging, especially across national borders, and in the era of decentralised government authorities and budgets.

4.4 Larger settlements have a large catchment area

At the level of individual suppliers, we quantified the relationship between size of supplying settlement (dependent variable) and distance to the study city (independent variable) using a linear regression model. The results revealed a significant positive effect of distance on settlement size and support hypothesis 4, that larger settlements have a larger catchment area (Fig. 5), with the strongest relationship for settlements supplying Ouagadougou ($\beta = 1.1$, $SE = 0.06$, $p = 0.000$, $Adj. R^2 = 45\%$; results for all cities in Table S6a: Supplementary Materials). This is unsurprising as Ouagadougou is one of the two capital cities with high reliance both on intra-regional trade and on larger cities, which in turn are associated with long-distance travel (see regional

level results in the next section). The analysis also confirms that food supply to a given city came mostly from smaller settlements close to the city, and larger settlements further away from the city, which may be aggregation centres for more remote producers. However, it is important to note that villages and small towns can still connect to cities further away, but they are usually not among the major suppliers. Most significant relationships ($p < 0.01$) were found among staple crops, including cereals, legumes, and roots and tubers, while perishable foods and livestock showed a less distinct relationship between distance and supplying settlement size (Table S6b & Fig. S3: Supplementary Materials).

This relationship between catchment size and settlement size does not only apply to supplying settlements but also to the study cities, where the average flow distance decreased with population size: On average, food travelled 240 km from source to Bamako, 211 km to Ouagadougou, the two capital cities, and 117 km to Tamale, and 97 km to Bamenda. A central location along a major trade corridor and direct road connection to national production hotspots may explain the slightly longer flow distance for Tamale compared to Bamenda, both cities of similar size.

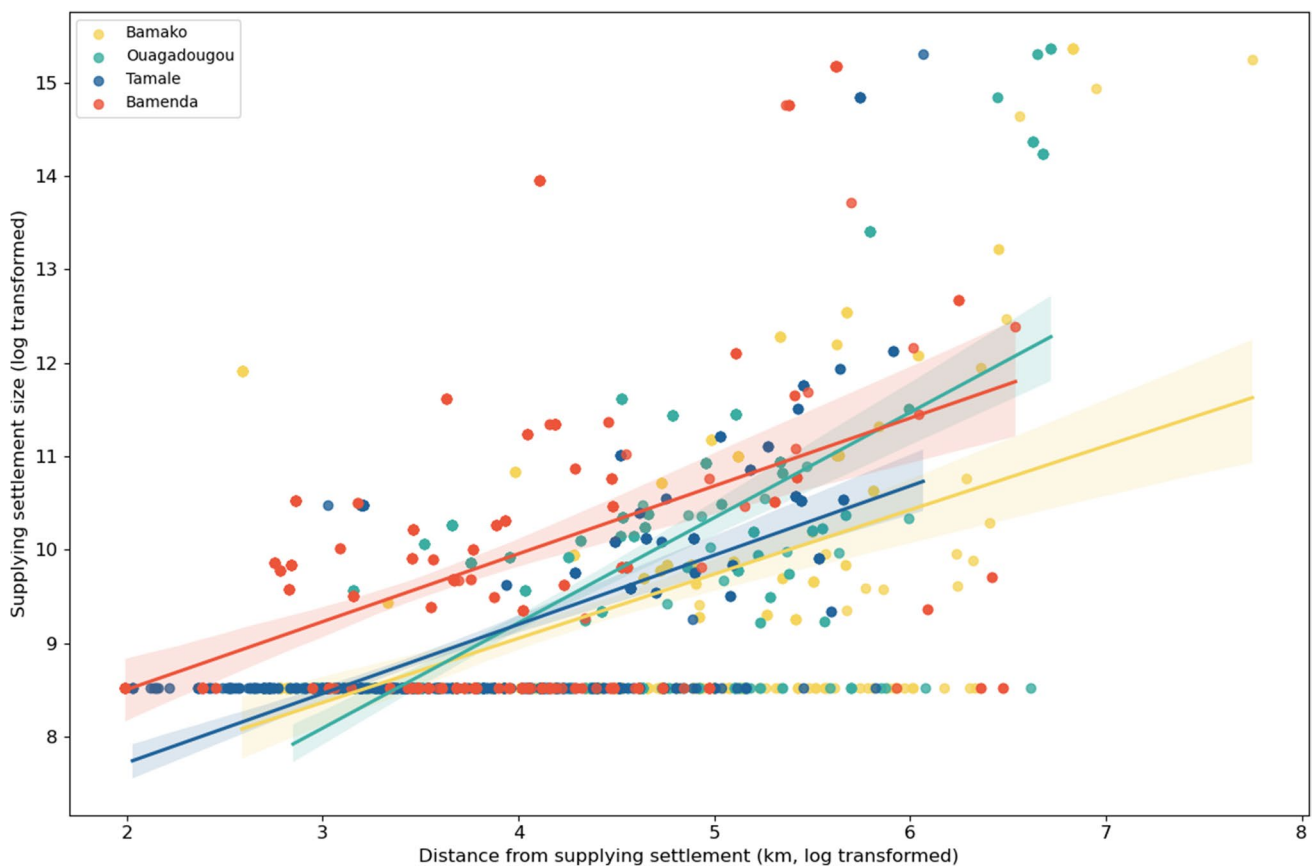


Fig. 5 Relationship between distance (km, log transformed) and settlement size (population, log transformed) based on supplying settlements for the four cities Bamako (Mali), Ouagadougou, (Burkina

Faso), Tamale (Ghana), and Bamenda (Cameroon). Result of linear regression model shown in Table S6a: Supplementary Materials

4.5 Larger settlements supply larger quantities

We conducted a linear regression analysis to examine the relationship between product-specific relative quantity (%) (dependent variable) and settlement size (independent variables). Our results partly support hypothesis 5, that larger settlements supply larger quantities. We see a significant positive relationship between relative product-specific quantities supplied by a settlement (%) and its size for all study sites but Bamenda (Fig. 6; Table S7a: Supplementary Materials). The relationship is strongest for Tamale ($\beta = 4.0$, $SE = 0.3$, $p = 0$, $Adj. R^2 = 26\%$), followed by Bamako ($\beta = 2.2$, $SE = 0.3$, $p = 0$, $Adj. R^2 = 14\%$) and Ouagadougou ($\beta = 1.8$, $SE = 0.2$, $p = 0$, $Adj. R^2 = 10\%$). We use relative quantity to be able to compare reliance on different settlement types across cities, however, one must note that Bamako and Ouagadougou would show the strongest relationship between quantity and source size when using absolute quantities. This is in line with the gravity model stipulating that large masses gravitate toward one another, and not surprising given larger cities require more food. Overall, the relationship is weaker than that between distance and supplying settlement size (Fig. 5).

Thus, on average, and for all cities but Bamenda, larger settlements supply larger relative quantities. However, there is high variability in quantities provided by different settlement classes, and rural areas can also supply over 60% of a product (Fig. 6). The relationships were weaker for perishable products than staple crops, indicating that trade of perishable products follows a less strict hierarchical pattern, and Bamenda showed less distinct hierarchical patterns overall (Table S7b & Fig. S4: Supplementary Materials).

The regional level analysis provides more insight into the size and function of supplying settlements. On average, the capital cities were more dependent on other cities with over 100,000 inhabitants than the secondary cities Bamenda and Tamale were. Cities supplied 24% and 33% of total inflows to Bamako and Ouagadougou, respectively, vs. only 16% and 12% for Bamenda and Tamale, respectively (Table S5: Supplementary Materials). Cities as suppliers were often associated with products travelling long distances, e.g., plantain, yam, and orange to Bamako and Ouagadougou. Larger cities often act as hubs, containing large markets (e.g., Bobo-Dioulasso in Burkina Faso, or Kumasi in Ghana) or ports (e.g., Abidjan, Côte d'Ivoire; Lomé, Togo, and Tema, Ghana).

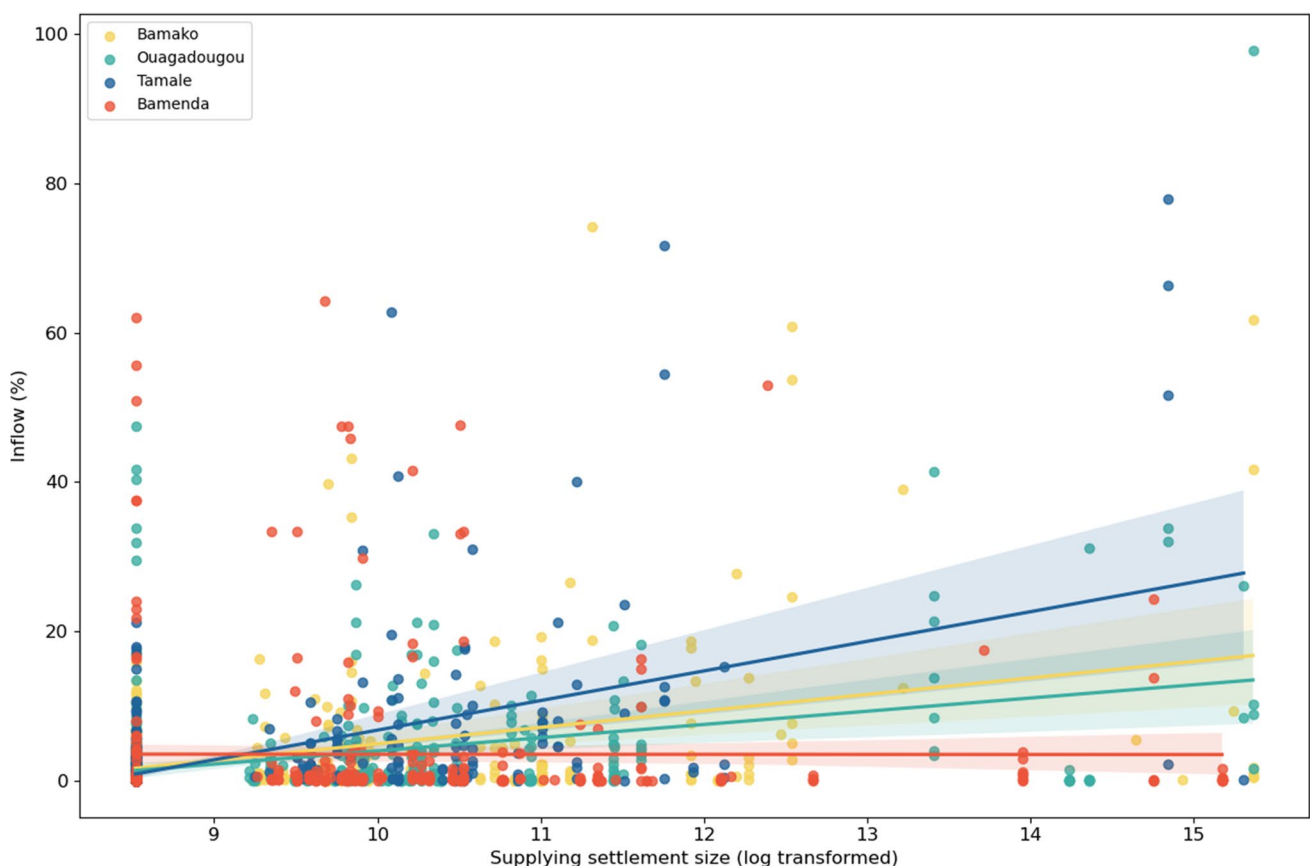


Fig. 6 Relationship between supplying settlement size (log transformed) and product-specific quantity (%) based on supplying settlements for the four cities Bamako (Mali), Ouagadougou, (Burkina

Faso), Tamale (Ghana), and Bamenda (Cameroon). Result of linear regression model shown in Table S7a: Supplementary Materials

Of all study cities, Tamale relied most on rural suppliers, with 47% of food flows coming from rural areas, vs. 32%, 29% and 16% for Bamenda, Bamako and Ouagadougou, respectively. Rural areas can be associated with primary production directly from the farm gate without prior aggregation, or from a rural market serving as an outlet for local farmers. In these cases, the city may act as an aggregation centre. Accordingly, a significant proportion of products from the hinterland within 50 km of the cities came from rural suppliers, with shares ranging from 37% (Bamenda) to 90% (Tamale; Ouagadougou: 51%; Bamako: 78%; Tables S2c & S5: Supplementary Materials). The city-specific differences in the type of hinterland suppliers can be attributed to the settlement structure in the cities' hinterland. For instance, Bamenda is in a densely populated region with a large number of small towns in its hinterland, a likely reason for the weak relationship between distance and supplying settlement size.

Inflows from towns with populations between 10,000 and 100,000 showed less variation and ranged from 41% (Tamale) through 48% (Bamako) to 52% (Ouagadougou and Bamenda). Thus, towns are major suppliers to all study cities but Tamale as they often act as assembly markets attracting produce, in particular cereals, roots, and tubers, from nearby rural production zones or rural markets (Elbehri et al., 2013). This is reflected in the data: on average, 57% of domestically produced staples entering Bamako and Ouagadougou came from towns as compared with 50% and 37% in Bamenda and Tamale, respectively (including cereals, roots, tubers, plantains, and legumes; excluding yam and plantains for Bamako and Ouagadougou). These towns were often located within the country beyond hinterlands. From there, 46% (Tamale) to 76% (Bamenda; Ouagadougou: 54%; Bamako: 60%) of the food inflows, particularly staples, came from towns (Table S5: Supplementary Materials).

4.6 Quantity traded is not always related to distance but to different functions of urban and rural places

Our data showed no clear relationship between overall food quantities supplied and the distance between supplier and destination, so hypothesis 6 was not fully supported. Rather, the data showed the different roles of various types of space and settlement in food systems, reflected in various crop-specific supply patterns.

All cities relied to some extent on their hinterlands, defined as a 50 km radius around the cities, but for different produce: in Bamako and Ouagadougou, intensive peri-urban vegetable production dominated crop production around the capital cities, supplying consumers through urban wet markets. In contrast, Tamale was more integrated into its traditional agricultural hinterland dominated by staple food

production and Bamenda relied on its hinterland for a range of products (Fig. 4). Related to this, it is important to note that the 50 km radius defined as 'hinterland' may not perform the same function in cities of different sizes: around large cities the peri-urban zone, often defined as a dynamic transition zone between the city and the countryside (Karg et al., 2019b; Simon et al., 2004), may extend further than around smaller cities, where the hinterland is characterised by a large fraction of rural areas. With increasing size of a city, its sphere of influence extends further, and large areas of the surrounding countryside are devoted to meeting the urban demand, especially for fresh perishable produce, given the lack of cold chains (Moustier et al., 2023). On the other hand, smaller cities have weaker influence on their surrounding hinterland, given the overall lower demand for food, but also more traditional lifestyles and consumption patterns and less densely built-up inner urban areas, offering more options for urban agriculture (Bellwood-Howard et al., 2018). Therefore, flow distance alone does not characterise a local food system.

The previous sections showed that local, often rural, suppliers tended to provide smaller shares each, and distant places were often related to larger settlements, often representing aggregation centres, which tended to provide large quantities given good road access. Therefore, the distance food travels also depends on the position of a given study city in the food supply system, i.e., the larger capital cities relied relatively more on larger, distant suppliers compared to the two smaller cities Bamenda and Tamale. Eventually, the location of the study city played a role as agricultural suitability gradients also partly drove food flows even over longer distances, and distance outweighed complementarity only where suitability gradients were less steep. It is therefore not always possible to distinguish clearly between cause and effect, as factors interact.

4.7 Concentration and spatial scale in supply chains

Having addressed our 6 hypotheses, we shift the level of analysis from the individual supplier to the supply chain of a product, to allow a comparison between different products and cities. Here, supply chain refers to all product- and city-specific suppliers and their potential respective upstream suppliers. One relevant metric is the highest overall share of a product supplied by one settlement, which gives insights into the level of reliance on a single supplier, and therefore into the level of concentration of a supply chain. A low maximum share indicates low concentration, that is, a more balanced, diversified reliance on several suppliers (from many primary producers or low-level markets supplying small shares each). The level of concentration from one supplier varied considerably (Fig. 7).

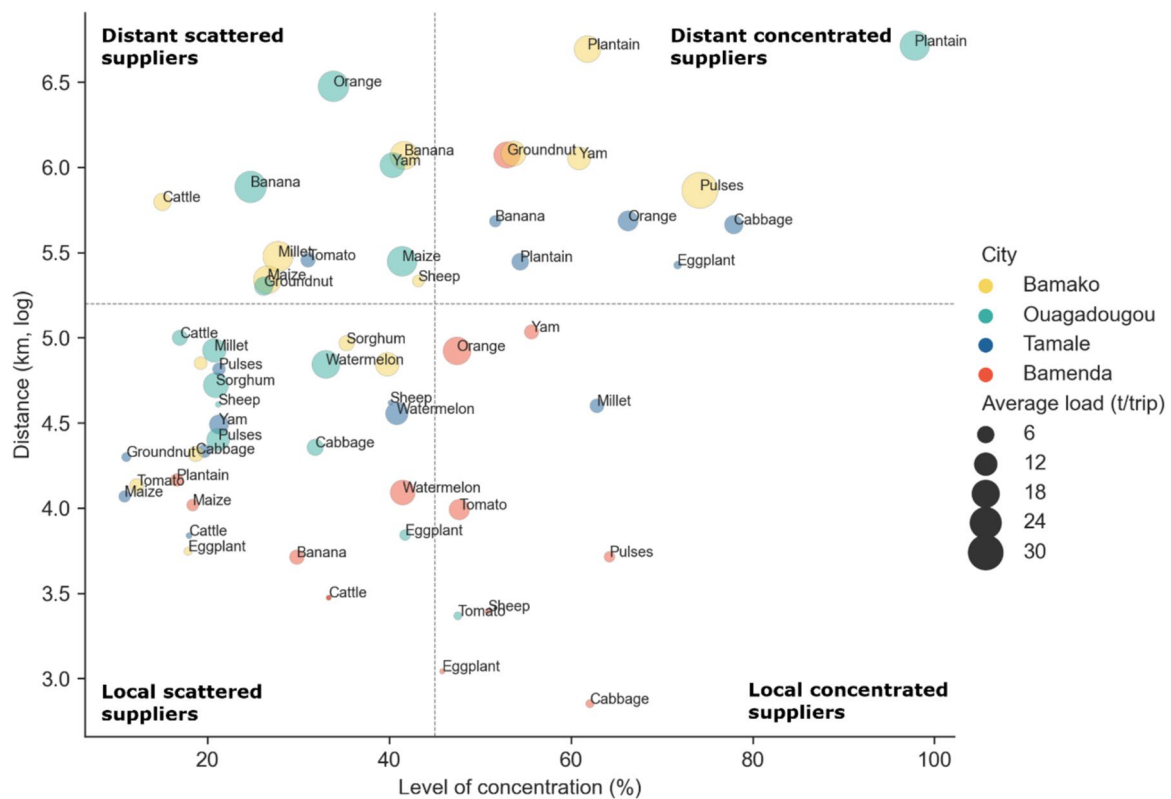


Fig. 7 Level of concentration (%; x-axis) and distance (km, log transformed, weighted mean, y-axis). Symbol size reflects average load per trip (weighted mean). The level of concentration refers to the

most dominant supplier; distance is the weighted mean across all suppliers. The quadrants are divided at 45% concentration level and a log-km distance of 5.2 (translating into 180 km)

Levels of concentration were only weakly related to average distance, supplying settlement size, and transport load per trip (weighted means; aggregated at the level of product and city), whereas the latter three factors were strongly correlated (Fig. S5: Supplementary Materials). The increase of average transport loads with travel distance is expected as long-distance transportation requires large vehicles carrying heavy loads to reduce the cost per unit quantity and distance (Tracey-White, 2005).

Plotting levels of concentration against distance therefore shows a high variance of supply chains along distance and concentration levels (Fig. 7), reflecting the different contexts in which cities sourced their food, including agroecological zone and road access.

For instance, Bamenda and Tamale were highly integrated into their (wider) agricultural hinterland, as they often sourced from several rural suppliers, or *local scattered suppliers*. These included staple crop suppliers for Bamenda (plantain, maize) and Tamale (maize, yam) making use of favourable agricultural conditions for these crops. Thereby, these cities acted as aggregators, as in the case of Tamale from where maize and yam are transported to other major urban centres (Karg et al., 2022). Capital cities depended less on their immediate hinterland for

staple crops, but rather for higher-value vegetables. For instance, different farms in Bamako's hinterland supplied the city with vegetables, predominantly for consumption.

Higher levels of concentration from *local concentrated suppliers* suggest that produce had already been aggregated in the case of staples, e.g., in Bamenda (yams from border villages, pulses from hinterland towns) or came from specialised production areas in the case of vegetables. For instance, Loumbila, site of a reservoir 20 km north of Ouagadougou used by market gardeners for irrigation, was one hotspot for the commercial production of vegetables, such as tomato.

Average transport loads from local suppliers were small compared to distant suppliers and suggest the integration of small-scale actors into local supply chains, regardless of whether the settlement was a major supplier overall.

Distant scattered suppliers, often medium-sized towns, supplied the capital cities with products such as maize and cattle and by doing so revealed their central status in terms of geography as well as economy, connected to many parts of the country by good road networks. These suppliers very likely source from primary producers and small-town markets within their own, smaller catchment.

Distant concentrated suppliers were found for all cities for different products. The differences are due to complementary supply of goods relative to the cities' own agroecological zone and included dominant, distant national suppliers (e.g., groundnut from Northern Cameroon to Bamenda) or products traded across the border (e.g., plantain to Bamako and Ouagadougou). The precondition for supply from these places is good road access to reduce travel time and costs. For instance, Tamale sourced many vegetables and fruits from the central part of Ghana, on a direct primary road connection. Some of these concentrated suppliers represent aggregating towns; others may represent rural areas, which specialise in production of a crop type, possibly due to advantage compared to other locations, which can be affected by suitability for a given crop as well as by relative availability of the relevant factors of production (Overman et al., 2003; Pellegrina, 2016), which are challenging to quantify in our study locations.

The degree of concentration is also likely to be influenced by other more qualitative cultural, historical, and political factors that may have enhanced the reputation of a place as a production area for given goods or contributed to development of socially embedded trade networks (Rauch & Trinidad, 2002; Overmann et al., 2003). For instance, Torres and van Seters (2016) and Lyon and Porter (2010) described how trade relationships are shaped by shared language, social networks, and trust. Hill (1966) noted that for some West African political jurisdictions, marketplaces played roles associated with political control or revenue collection, in addition to economic functions. Historical locations of markets may persist when they no longer play their original function, as places have gained a reputation for hosting markets, sometimes of specific goods (Bromley et al., 1975). Loumbila, mentioned above, provided over 40% of cabbages and eggplants to Ouagadougou. Akum, the location of an irrigation scheme started in 2013, funded by the African Development Bank, supplied over 60% of cabbages to Bamenda. Historical markets include San, Mali, sited on an important road between South and North Mali, which supplied 74% of cabbages to Bamako; the large and famous market city of Kumasi, historic centre of the Ashanti empire, which supplied 77% of cabbages and 66% of oranges to Tamale; and the large town of Techiman, crossroads between northern and Southern Ghana, which supplied 71% of eggplant and 54% of plantain to Tamale. The presence of Sikasso in the data as supplying over 50% of oranges and yams to Bamako probably represents both production and aggregation functions — Sikasso is a southern Malian region well-known for agricultural production. The regional capital, Sikasso city, was capital of the historical Kénédougou empire, and became the site of a large market which remains important in the modern day due to proximity to the Burkinabe and Ivorian borders. Smaller flows of goods were visible in the

data towards Tamale from other towns in northern Ghana's historical periodic market system.

Thus, some of the supplier locations appear in the data not only because of their size or distance from the destination city, but also because their suitability for various crops has been shaped by development projects, or because they hosted historically important markets. It is likely these macro- and micro-level qualitative factors play some role in establishing dominance of a given location in specific trade flows, measured by concentration in our data. These factors may interact in such a way that it is not meaningful to attribute ultimate causality, for example in the case that a reputational connection with a certain agricultural product may encourage labour migration to an area (Ottaviano & Thisse, 2004).

4.8 Limitations and further research

Our study faced challenges with the availability and appropriateness of secondary data, which could be addressed with further research. The GAEZ4 data on agricultural suitability do not adequately reflect the suitability of West African regions for vegetables and small-scale production. For instance, according to those data, suitability to produce cabbage is zero, yet our data show cabbage is produced. Another data quality issue concerns Bamenda, located in the highly productive Western Highlands of Cameroon, which according to GAEZ4 data often has lower suitability values than the other countries. Future work would benefit from development of more regional and crop-specific suitability indices.

The primary data on food flows is 7–11 years old, which we do not consider a limitation per se, because there is no evidence to suggest that major changes have taken place in the region to do with the core concerns of this study, i.e., the type or location of food produced and consumed, or the mechanisms of how food reaches urban consumers via markets, given that traditional marketplaces still have a major role to play in the distribution of food. However, it is likely that the demand for high-value products, including fruits, vegetables, and meat, has increased due to factors outlined in section 2, such as demographic change and nutrition transition. The increase in demand may be met by expansion and intensification of current production, expansion towards more marginalised regions, or increased imports. A more current dataset on food flows therefore may include more different source locations and larger quantities from existing sources.

Another concern is the limited choice of indicators describing the context in which the cities source food. This paper focuses on indicators of biogeographical and infrastructural factors required to produce and trade agricultural products. Yet, at several points we have noted the importance of factors related to and interacting with our indicators,

including institutional settings, tariff regimes, historical path dependencies, and networks between supply chain actors. To fully understand the development and food security implications of the flows we describe in this paper, they must be contextualised within the understanding of the wider urban food system that has emerged in Afro-centric food literature since 2015, with particular attention to the hybrid nature of governance of African urban centres and rural–urban linkages (Haysom & Battersby, 2023; Haysom, 2015; Nchanji & Bellwood-Howard, 2018; Smit, 2016). Infrastructure and services play a role in shaping how food flows, but the implications for different groups are also informed by other formal and informal regulations and norms influenced by multiple institutions, including trader associations, political and civil society interest groups, and traditional authorities alongside local and national governments. Thus, data on quantitative food flows needs to be supplemented with answers to questions about, for example, who bears the burden of informal and formal tolls and taxation; how access to markets is governed through formal and informal associations and norms; how micro-political allegiances are expressed in import policy and practice, and who is able to obtain loans and credit to trade goods, and why.

4.9 Policy implications

Though the scope of this paper does not extend to full incorporation of the governance aspects acknowledged in the previous section, we are able to highlight key policy implications related to urban food security and livelihoods along supply chains.

4.9.1 Improving infrastructure for food systems

Improved primary and secondary road infrastructure would facilitate more efficient, i.e., less wasteful, market links between cities and urban and rural sources, as well as connecting rural primary sources to aggregation hubs, which are major suppliers to large cities. Better secondary road networks are particularly important to ensure rural producers and traders operating from small-scale specialised and aggregating sources can integrate into trade networks. Improved infrastructure also involves public storage: perishable products require refrigerated storage and cold chains (Alulu et al., 2023), or, more realistically in contexts with unreliable electrification, support for the very local supply chains starting in urban hinterlands. Such support can include rapid, reliable transport services and stall spaces for the smallest scale traders, and processing facilities for oil crops. Results in sections 4.4–4.5 show that settlements of different sizes source food from different types of area, so different types of transport infrastructure are differentially important for larger and smaller settlements. Yet, what is

more important for food systems, and actors within them, is that food is facilitated to flow across a catchment and between the settlements of varying size that exist within it. Thus, policy and governance actors should consider not only roads and vehicles, but also the transport and toll regimes and institutional connections that make this possible within already established catchments – which, our data showed, are larger for systems around a larger city, but also often shaped by historical or cultural factors, and therefore traverse administrative and even national boundaries.

4.9.2 Strengthening the role of intermediary markets

More and better crop-specific processing and storage infrastructure would develop the aggregation centres that link rural actors into trade routes. Investment in grain stores and bulking facilities for dry goods should take place in intermediary settlements and follow the hierarchical arrangements that traditional and periodic markets tend to follow. This would provide income to rural farmers as well as residents of rural settlements and intermediary towns and cities who are engaged in the post-harvest sector.

4.9.3 Formalisation and trade policy

As noted above, the food systems represented by the data are characterised by interactions across a gradient of formality. Torres and van Seters (2016) and Haggblade et al. (2012) argue for more widespread formalisation of trade, with tariff exemptions for informal traders. Formalisation could help if it allowed currently informal traders, who are often women, to access improved infrastructure without squeezing them out of the market due to higher costs. Otherwise, it is unclear how full formalisation would have a net positive effect on all the flows illustrated here, and the actors that already perform them: it entails costs, and some of the major barriers are inadequate public goods such as roads. Observations during data collection, and existing literature (Bellwood-Howard & Nchanji, 2017; Bellwood-Howard et al., 2021; Nchanji et al., 2023) show many people with insufficient levels of capital to operate larger businesses were gaining livelihoods by informally producing and trading food for cities. Border barriers are a clear trade impediment. This may be due to tariffs and legal restrictions, but also informal or illicit payments along the route (Akoto-Danso & Karg, 2020; Torres & van Seters, 2016). ECOWAS and the West African Economic and Monetary Union (WAEMU) as well as the African Continental Free Trade Area (AfCFTA) at the continental level aim for integration to avoid this type of tariff and barrier. However, implementation does not follow policies and illegal misapplication is common. National policies need to be harmonised with subregional ones, and traders need to be sensitised to the law to be able to challenge illegal tariffs.

However, with the withdrawal of Burkina Faso, Mali, and Niger from ECOWAS in the beginning of 2024, the already low level of cross-border trade is expected to decrease further at the cost of producers and consumers in the West African subregion.

These observations, as well as those on the role of historical and cultural factors (section 4.7), indicate that the effects of formal policy drivers will be mediated by other processes, and expectations of their reach should be tempered. Some cities have therefore experimented with convening different formal and informal governance actors in multistakeholder forums (e.g. Chirwa & Yossa, 2019; Haysom & Currie., 2022). These have often used the concept of ‘City Region Food Systems’, which acknowledges that urban food systems are nested within regional networks (Vittuari et al., 2021; Fei et al., 2023, FAO et al., 2023). Such forums may provide routes into dealing with the complexities of governing food systems that cross overlapping geographical and institutional domains, including internationally, as city governments need to coordinate with regions around them, as well as informal institutions, when considering transport, tolls, taxes, funding, collaborations etc. for food systems. Yet, it is also shown that such formalised multistakeholder processes may exclude extant vernacular governance actors such as non-unionised vendors (Haysom & Battersby, 2023), and the City Region Food Systems approach has not always been used in a way conducive to inclusion of such actors (Battersby, 2017). More practical work is therefore needed on contextually appropriate governance for contemporary African food systems.

4.9.4 Diversifying suppliers

Diversification of suppliers can enhance supply chain robustness, contributing to resilience of urban food supply (Zurek et al., 2022, Hertel et al., 2023). A supply chain may be more vulnerable to disruption when high concentration represents reliance on a single production site. When a supply chain is concentrated because a city relies heavily on one market, which in turn aggregates from many suppliers, this may be more resilient, because markets are more likely to be able to source from multiple production areas. Nevertheless, supply chains sourcing from scattered suppliers are likely to be most resilient, as diverse supply chains rely on a diversity of supplier types sourcing from near and far, which reduces potential food supply chain instability and shocks. The risks of relying on single and particularly international suppliers were illustrated in Covid-19 lockdowns when cross-border trade was temporarily interrupted, obliging governments to provide emergency food supplies to many urban populations (Salm et al., 2022). Disruption of markets, especially concentrated ones, also has implications for producers, who need to find alternative outlets. Ability to switch between

outlets and suppliers relies on the road and border factors highlighted by hypotheses 2 and 3, as well as storage infrastructure.

5 Conclusion

This study aimed to better understand factors linking different West African cities with food production areas, including supplying settlement size and type, distance, agricultural complementarity, and road access. The current context of urbanisation is increasing demand for food. Understanding how different supply chains link into different types of urban settlements in West African food systems can inform policies for optimising those processes and systems to provide food and income more effectively to rural and urban groups.

Our findings reveal a hierarchical food supply system, with small-scale producers in the close catchment area and hinterland of cities supplying directly to cities, often from rural areas, and those further afield supplying to other aggregation centres, which supply onwards to cities. The larger the aggregation centre, the further away it will send goods. This pattern confirms basic principles of the CPT, in which smaller settlements with small catchments are nested within the larger catchments of larger settlements. The position of the focal city within this system explains to some extent its reliance on either predominantly rural nearby suppliers or more distant larger suppliers, for example, larger, capital cities are more reliant on larger suppliers further away. This is particularly applicable to storable staples; perishables have fewer intermediaries and therefore less hierarchical supply chains. Areas with low suitability for a certain good are likely to source it from areas with higher suitability, but international borders impede that transportation, although good road access facilitates all such movement. These results show that spatial models do help explain how trade is facilitated, however, the trade patterns seen are also likely to be influenced by historical, cultural, political, and social factors. International borders are one such factor, but it was also observed that key trade and production locations were influenced by development projects such as irrigation schemes and continued importance of historical seats of power.

Our results confirm what is already known about the conditions that facilitate trade, which includes improved road infrastructure between cities and urban and rural suppliers, as well as between rural primary suppliers and aggregation hubs. More and better crop-specific processing and storage infrastructure would develop these aggregation centres that link rural actors into trade routes.

It is likely that rising food demand can lead to opportunities for the markets described in this paper to provide food in ways that meet nutritional needs while providing viable income generating opportunities to a range of male

and female rural producers and rural and urban traders. Appropriate infrastructural provision that supports existing market routes is required for any such increases in commercialisation to result in more equitable, efficient, and resilient consumption, production and trade opportunities for local people (de Bruin et al., 2021; Wiggins et al., 2011). Governance forums that facilitate cross regional and interinstitutional collaboration are likely to support this, and research on hybrid food system governance will enhance understanding of how to achieve it.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s12571-025-01518-8>.

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Data Availability All data sources are publicly available. The code for reproducing the analysis can be found at <https://github.com/HannaKarg/food-supply-model>.

Declarations

Competing interest Authors declare that there are no financial or non-financial interests and no competing interests.

Ethical approval No ethical approval was required.

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